

CLAIMS

We claim:

- 1 1. A phase shift device, comprising:
 - 2 a first superconducting terminal, having a first phase;
 - 3 a second superconducting terminal, having a second phase; and
 - 4 a phase shifter, coupled to the first superconducting terminal and to the
 - 5 second superconducting terminal, wherein
 - 6 the phase shifter is capable of causing a predefined difference
 - 7 between the first phase and the second phase.
- 1 2. The phase shift device of claim 1, wherein
 - 2 the phase shifter comprises an anisotropic superconductor.
- 1 3. The phase shift device of claim 2, wherein
 - 2 the anisotropic superconductor is a d-wave superconductor.
- 1 4. The phase shift device of claim 2, wherein
 - 2 the first superconducting terminal and the second superconducting
 - 3 terminal comprise s-wave superconductors.
- 1 5. The phase shift device of claim 2, wherein
 - 2 the anisotropic superconductor is coupled to the first superconducting
 - 3 terminal through a first side; and
 - 4 the anisotropic superconductor is coupled to the second
 - 5 superconducting terminal through a second side; wherein
 - 6 the first side and the second side define a mismatch angle.
- 1 6. The phase shift device of claim 5, wherein
 - 2 the mismatch angle is about 90 degrees.

1 7. The phase shift device of claim 2, wherein
2 the phase shifter is electrically coupled to the first superconducting
3 terminal through a first connector; and
4 the phase shifter is electrically coupled to the second superconducting
5 terminal through a second connector.

1 8. The phase shift device of claim 7, wherein
2 the first superconducting terminal, the second superconducting
3 terminal, the first connector, the second connector, and the phase shifter
4 overlie a substrate.

1 9. The phase shift device of claim 8, wherein
2 the first connector is adjacent to the phase shifter;
3 the first superconducting terminal is adjacent to the first connector;
4 the second connector is adjacent to the phase shifter; and
5 the second superconducting terminal is adjacent to the second
6 connector.

1 10. The phase shift device of claim 7, wherein
2 the first connector and the second connector comprise normal metals.

1 11. The phase shift device of claim 2, wherein
2 the length and the width of the first superconducting terminal and the
3 length and the width of the second superconducting terminal are less than
4 about 5 microns, wherein

5 the first superconducting terminal and the second
6 superconducting terminal have length and width.

1 12. The phase shift device of claim 2, wherein
2 the coupling of the phase shifter and the first superconducting terminal
3 comprises a first Josephson junction; and

4 the coupling of the phase shifter and the second superconducting
5 terminal comprises a second Josephson junction.

1 13. The phase shift device of claim 2, wherein

2 the first superconducting terminal and the second superconducting
3 terminal comprise niobium, aluminum, lead, or tin;

4 the phase shifter comprises $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$, wherein d has a value
5 between about 0 and about 0.6; and

6 the first connector and the second connector comprise gold, silver, or
7 platinum.

1 14. The phase shift device of claim 2, wherein the phase shifter comprises:
2 a plurality of anisotropic superconductors.

1 15. The phase shift device of claim 14, wherein the phase shifter
2 comprises:

3 a first anisotropic superconductor; and

4 a second anisotropic superconductor, wherein

5 the first superconductor and the second superconductor are
6 coupled by a Josephson-junction.

1 16. The phase shift device of claim 15, wherein the Josephson-junction
2 comprises:

3 a grain boundary.

1 17. The phase shift device of claim 15, wherein

2 the first anisotropic superconductor has a first order parameter with a
3 first orientation, and

4 the second anisotropic superconductor has a second order parameter
5 with a second orientation, wherein

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377/

6 the first orientation and the second orientation define a
7 mismatch angle.

1 18. The phase shifter device of claim 17, wherein
2 the mismatch angle is about 45 degrees.

1 19. The phase shift device of claim 15, wherein
2 the first anisotropic superconductor and the second anisotropic
3 superconductor overlie a substrate.

1 20. The phase shift device of claim 19, wherein
2 the first connector overlies the first anisotropic superconductor; and
3 the second connector overlies the second anisotropic superconductor.

1 21. The phase shift device of claim 20, wherein
2 the first superconducting terminal overlies the first connector; and
3 the second superconducting terminal overlies the second connector.

1 22. The phase shift device of claim 1, wherein the phase shifter comprises:
2 a ferromagnet.

1 23. The phase shift device of claim 22, wherein
2 the ferromagnet is an alloy of copper and nickel.

1 24. The phase shift device of claim 22, wherein
2 the first superconducting terminal overlies a substrate;
3 the ferromagnet overlies the first superconducting terminal; and
4 the second superconducting terminal overlies the ferromagnet.

1 25. The phase shift device of claim 24, wherein

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the second superconducting terminal is isolated from the first superconducting terminal by an insulator.

26. The phase shift device of claim 25, wherein

the insulator is polymethylmethacrylate or AlO_x , wherein x is an integer.

27. The phase shift device of claim 24, wherein

the length and width of the first superconducting terminal, the ferromagnet and the second superconducting terminal, and

the relative position of the first superconducting terminal, the ferromagnet and the second superconducting terminal is such that they cause a predefined difference between the first phase and the second phase, wherein

the first superconducting terminal, the ferromagnet and the second superconducting terminal have a length, a width, and a relative position.

28. The phase shift device of claim 22, wherein

the first superconductor terminal and the second superconductor terminal are coupled by a junction area; and

the ferromagnet is embedded in the junction area.

29. The phase shift device of claim 28, wherein

the length and width of the first superconducting terminal, the ferromagnet and the second superconducting terminal, and

the relative position of the first superconducting terminal, the ferromagnet and the second superconducting terminal is such that they cause a predefined difference between the first phase and the second phase, wherein

the first superconducting terminal, the ferromagnet and the second superconducting terminal have a length, a width, and a relative position.

- 1 30. The phase shift device of claim 1, further comprising:
2 a conventional superconducting terminal, coupled to the first
3 superconducting terminal by a first junction, and coupled to the second
4 superconducting terminal by a second junction,
5 the first superconducting terminal, the second superconducting
6 terminal, and the conventional superconducting terminal forming a
7 loop.
- 1 31. The phase shift device of claim 30, wherein
2 the first and second junctions are c-axis heterojunctions.
- 1 32. The phase shift device of claim 30, wherein
2 the predefined difference between the first phase and the second phase
3 is about $\pi/2$.
- 1 33. A phase shift device, comprising:
2 a first superconducting terminal means, having a first phase;
3 a second superconducting terminal means, having a second phase; and
4 a phase shifter means, coupled to the first and second superconducting
5 terminal means, capable of causing a predefined difference between the first
6 phase and the second phase.
- 1 34. The phase shift device of claim 33, wherein
2 the phase shifter means comprise a d-wave superconductor.
- 1 35. A phase shifting method, the method comprising:
2 providing a first superconducting terminal, having a first phase;
3 providing a second superconducting terminal, having a second phase;
4 and
5 coupling a phase shifter to the first superconducting terminal and to the
6 second superconducting terminal, wherein

7 the phase shifter is capable of causing a predefined difference
8 between the first phase and the second phase.

1 36. The method of claim 35, wherein providing a phase shifter comprises:
2 providing an anisotropic superconductor.

1 37. The method of claim 35, wherein coupling the phase shifter comprises:
2 coupling the first superconducting terminal to a first side of the phase
3 shifter;

4 coupling the second superconducting terminal to a second side of the
5 phase shifter, wherein

6 the first side and the second side of the phase shifter define a
7 mismatch angle.

1 38. The method of claim 37, wherein
2 coupling the first superconducting terminal to the first side of the phase
3 shifter comprises:

4 coupling the first superconducting terminal to a first connector,
5 and

6 coupling the first connector to the phase shifter; and

7 coupling the second superconducting terminal to the second side of the
8 phase shifter comprises:

9 coupling the second superconducting terminal to a second
10 connector, and

11 coupling the second connector to the phase shifter.

1 39. The method of claim 35, wherein providing the phase shifter
2 comprises:

3 providing a first anisotropic superconductor, having a first order
4 parameter with a first orientation, and

5 providing a second anisotropic superconductor, having a second order
6 parameter with a second orientation, wherein
7 the first orientation and the second orientation define a
8 mismatch angle.

1 40. The method of claim 35, wherein providing the phase shifter
2 comprises:

3 coupling the first superconducting terminal and the second
4 superconducting terminal with a junction; and
5 providing a ferromagnet in the junction.

1 41. A phase shifter circuitry, comprising:

2 a phase shift device, comprising:

3 a first superconducting terminal, having a first phase;
4 a second superconducting terminal, having a second phase; and
5 a phase shifter, coupled to the first superconducting terminal
6 and to the second superconducting terminal, wherein
7 the phase shifter is capable of causing a predefined
8 difference between the first phase and the second phase; and
9 superconducting circuitry, coupled to the phase shift device.

1 42. The phase shifter circuitry of claim 41, wherein

2 the phase shifter comprises an anisotropic superconductor.

1 43. The phase shifter circuitry of claim 41, wherein

2 the anisotropic superconductor is coupled to the first superconducting
3 terminal through a first side; and

4 the anisotropic superconductor is coupled to the second
5 superconducting terminal through a second side; wherein

6 the first side and the second side define a mismatch angle.

1 44. The phase shifter circuitry of claim 41, wherein
2 the phase shifter is electrically coupled to the first superconducting
3 terminal through a first connector; and
4 the phase shifter is electrically coupled to the second superconducting
5 terminal through a second connector.

1 45. The phase shifter circuitry of claim 41, wherein
2 the first superconducting terminal and the second superconducting
3 terminal comprise niobium, aluminum, lead, or tin;
4 the phase shifter comprises $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$, wherein d has a value
5 between about 0 and about 0.6; and
6 the first connector and the second connector comprise gold, silver, or
7 platinum.

1 46. The phase shifter circuitry of claim 41, wherein the phase shifter
2 comprises:
3 a first anisotropic superconductor, having a first order parameter with a
4 first orientation; and
5 a second anisotropic superconductor, having a second order parameter
6 with a second orientation, wherein
7 the first orientation and the second orientation define a
8 mismatch angle; and
9 the first superconductor and the second superconductor are
10 coupled by a Josephson-junction.

1 47. The phase shifter circuitry of claim 41, wherein
2 the first anisotropic superconductor and the second anisotropic
3 superconductor overlie a substrate;
4 the first connector overlies the first anisotropic superconductor;
5 the second connector overlies the second anisotropic superconductor;

6 the first superconducting terminal overlies the first connector; and
7 the second superconducting terminal overlies the second connector.

1 48. The phase shifter circuitry of claim 41, wherein
2 the first superconducting terminal overlies a substrate;
3 a ferromagnet overlies the first superconducting terminal; and
4 the second superconducting terminal overlies the ferromagnet.

1 49. The phase shifter circuitry of claim 48, wherein
2 the first superconductor terminal and the second superconductor
3 terminal are coupled by a junction area; and
4 the ferromagnet is embedded in the junction area.

1 50. The phase shifter circuitry of claim 41, wherein
2 the phase shift device overlies a substrate;
3 the superconducting circuitry overlies the phase shift device; and
4 a first contact terminal and a second contact terminal couples the
5 superconducting circuitry and the phase shift device.

1 51. The phase shifter circuitry of claim 50, wherein
2 the substrate is sapphire or SrTiO_3 .

1 52. The phase shifter circuitry of claim 50, wherein
2 an insulating layer separates the phase shift device and the
3 superconducting circuitry, wherein
4 the first contact terminal and the second contact terminal
5 couples the superconducting circuitry and the phase shift device
6 through a first opening and a second opening in the insulating layer,
7 respectively.

1 53. The phase shifter circuitry of claim 41, wherein

2 the superconducting circuitry overlies a substrate;
 3 the phase shift device overlies the superconducting circuitry; and
 4 a first contact terminal and a second contact terminal couples the
 5 superconducting circuitry and the phase shift device.

1 54. The phase shifter circuitry of claim 53, wherein
 2 an insulating layer separates the phase shift device and the
 3 superconducting circuitry, wherein
 4 the first contact terminal and the second contact terminal couples the
 5 superconducting circuitry and the phase shift device through a first opening
 6 and a second opening in the insulating layer, respectively.

1 55. The phase shift circuitry of claim 41, wherein the superconducting
 2 circuitry comprises:
 3 quantum computing circuitry.

1 56. A phase shifter circuitry, comprising:
 2 a phase shift device means, comprising:
 3 a first superconducting terminal means, having a first phase;
 4 a second superconducting terminal means, having a second
 5 phase; and
 6 a phase shifter means, coupled to the first and second
 7 superconducting terminal means, capable of causing a predefined
 8 difference between the first phase and the second phase;
 9 and
 10 a superconducting circuitry means, coupled to the phase shifting
 11 means.

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1 57. A phase shifting method, the method comprising:
2 providing a phase shift device, comprising:
3 providing a first superconducting terminal, having a first phase;
4 providing a second superconducting terminal, having a second
5 phase; and
6 coupling the first superconducting terminal and the second
7 superconducting terminal to a phase shifter, wherein
8 the phase shifter is capable of causing a predefined
9 difference between the first phase and the second phase; and
10 coupling a superconducting circuitry to the phase shift device.

1 58. The method of claim 57, wherein providing a phase shifter comprises:
2 providing an anisotropic superconductor.

1 59. A phase shifter chip, comprising:
2 a plurality of phase shift devices, the phase shift devices individually
3 comprising:
4 a first superconducting terminal, having a first phase;
5 a second superconducting terminal, having a second phase; and
6 a phase shifter, coupled to the first superconducting terminal
7 and to the second superconducting terminal, wherein
8 the phase shifter is capable of causing a predefined
9 difference between the first phase and the second phase; and
10 superconducting circuitry, coupled to the plurality of phase shift
11 devices.

1 60. The phase shifter chip of claim 59, wherein the phase shifters
2 individually comprise:
3 an anisotropic superconductor.

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- 1 61. The phase shifter chip of claim 59, wherein
2 the first superconducting terminals and the second superconducting
3 terminals comprise niobium, aluminum, lead, or tin; and
4 the phase shifters individually comprise $\text{YBa}_2\text{Cu}_3\text{O}_{7-d}$, wherein d has a
5 value between about 0 and about 0.6.
- 1 62. The phase shifter chip of claim 59, wherein the phase shifters
2 individually comprise:
3 a first anisotropic superconductor, having a first order parameter with a
4 first orientation; and
5 a second anisotropic superconductor, having a second order parameter
6 with a second orientation, wherein
7 the first orientation and the second orientation define a
8 mismatch angle.
- 1 63. The phase shifter chip of claim 62, wherein
2 the mismatch angle is about 45 degrees.
- 1 64. The phase shifter chip of claim 59, wherein in the individual phase
2 shifters
3 the first anisotropic superconductors and the second anisotropic
4 superconductors are coupled by a Josephson-junction.
- 1 65. The phase shifter chip of claim 64, wherein
2 the Josephson junctions comprise a grain boundary.
- 1 66. The phase shifter chip of claim 59, wherein in the individual phase
2 shift devices
3 the first anisotropic superconductor and the second anisotropic
4 superconductor overlie a substrate;
5 the first superconducting terminal overlies the first anisotropic
6 superconductor; and



7 the second superconducting terminal overlies the second anisotropic
8 superconductor.

1 67. The phase shifter chip of claim 59, wherein
2 the plurality of phase shift devices overlie a substrate;
3 the superconducting circuitry overlies the plurality of phase shift
4 devices; and
5 the individual phase shift devices are coupled to the superconducting
6 circuitry by first contact terminals and second contact terminal.

1 68. The phase shifter chip of claim 67, wherein
2 an insulating layer separates the plurality of phase shift devices and the
3 superconducting circuitry, wherein in the individual phase shift devices
4 the first contact terminal and the second contact terminal
5 couples the superconducting circuitry and the individual phase shift
6 device through a first opening and a second opening in the insulating
7 layer, respectively.

1 69. The phase shifter chip of claim 59, wherein
2 the superconducting circuitry overlies a substrate;
3 the plurality of phase shift devices overlie the superconducting circuitry;
4 and
5 the individual phase shift devices are coupled to the superconducting
6 circuitry by first contact terminals and second contact terminals.

1 70. The phase shifter chip of claim 69, wherein
2 an insulating layer separates the plurality of phase shift devices and the
3 superconducting circuitry, wherein in the individual phase shift devices
4 the first contact terminal and the second contact terminal couples the
5 superconducting circuitry and the individual phase shift device through a first
6 opening and a second opening in the insulating layer, respectively.

1 71. The phase shifter chip of claim 59, wherein the superconducting
2 circuitry comprises:

3 quantum computing circuitry.

1 72. A phase shifter chip, comprising:

2 a plurality of phase shift device means, the individual phase shift
3 devices comprising:

4 a first superconducting terminal means, having a first phase;

5 a second superconducting terminal means, having a second
6 phase; and

7 a phase shifter means, coupled to the first and second
8 superconducting terminal means, capable of causing a predefined
9 difference between the first phase and the second phase; and

10 a superconducting circuitry means, coupled to the plurality of phase
11 shifting means.

1 73. A method of making a phase shifter chip, the method comprising:

2 forming a substrate with a first crystal axis orientation;

3 forming a seed layer with a second crystal axis orientation, overlying
4 the substrate, wherein the second crystal axis orientation is different from the
5 first crystal axis orientation,

6 forming a plurality of openings in the seed layer; and

7 forming a plurality of phase shift devices overlying the plurality of
8 openings.

1 74. The method of claim 73, wherein the forming of a plurality of phase
2 shift devices comprises:

3 forming a plurality of first anisotropic superconductors over the
4 plurality of openings; and

5 forming a plurality of second anisotropic superconductors over the
6 seed layer.

1 75. The method of claim 74, wherein the forming of a plurality of phase
2 shift devices comprises:

3 forming a plurality of first anisotropic superconductors, having first
4 order parameters with a first orientation; and

5 forming a plurality of second anisotropic superconductors, having
6 second order parameters with a second orientation, wherein

7 the first orientation is determined by the first crystal axis
8 orientation; and

9 the second orientation is determined by the second crystal axis
10 orientation.

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